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Sustainable development of smallholder crop-livestock farming in developing countries

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Abstract Meeting the growing demand for animal-sourced food, prompted by population growth and increases in average per-capita income in low-income countries, is a major challenge. Yet, it also presents significant potential for agricultural growth, economic development, and reduction of poverty in rural areas. The main constraints to livestock producers taking advantage of growing markets include; lack of forage and feed gaps, communal land tenure, limited access to land and water resources, weak institutions, poor infrastructure and environmental degradation. To improve rural livelihood and food security in smallholder crop-livestock farming systems, concurrent work is required to address issues regarding efficiency of production, risk within systems and development of whole value chain systems. This paper provides a review of several forage based-studies in tropical and non-tropical dry areas of the developing countries. A central tenet of this paper is that forages have an essential role in agricultural productivity, environmental sustainability and livestock nutrition in smallholder mixed farming systems.

1. Introduction

A large proportion of rural poor populations across the world derive a major share of their livelihood from mixed farming systems. Smallholder farming enterprises have a critical role in rural development and supporting local food systems through integrating multiple agricultural value chains from vegetables and fruits to animal products. Additionally, they provide a number of social and agro-ecological benefits such



as increased land use efficiency, improved biodiversity and access to affordable animal-source food for rural communities. These systems are threatened by population pressure, climate change, recurrent droughts and degradation of natural resources. These pressures are more acute in areas with climates that are marginal for existing practices [1]. In developing countries, the negative trends of unsustainable use of resources are often compounded by mismanagement, poor infrastructure, political instability, and ineffective socioeconomic policies. Addressing these issues will lead to improved sustainability, food security and rural livelihoods.

Forage plants sown for direct grazing, conservation or cover crops have a central role in agronomic sustainability and animal production in mixed crop-livestock farming systems. Benefits of forages include improved ruminant production, enhanced soil health and fertility, increased carbon sequestration, root disease management in cropping systems, increased biodiversity, and reduced economic risk through diversification [2] [3]. While the opportunities to expand the area of forage crops is limited due to the competition with field crops for land and water resources, increases in forage production may be possible through intercropping, alley cropping, or integration of legumes via crop rotation. Alternative fodder plants that are adapted to harsh climatic conditions and can be grown on lands unsuitable for cropping have significant potential for reducing the feed gap for livestock, improving animal health and contributing to food security and diversifying the income source of resource-poor farmers [4][5]. Revegetation of marginal land with perennials can lead to substantial increases in environmental health, including reduced soil salinity, increased carbon sequestration and reduced methane emissions from ruminants[6]. Developing varieties and management techniques for dual purpose (food-feed) legumes and cereals, cover crop grazing techniques, and intensifying cropping systems (by replacing fallows with feed and forage legumes) are promising options[7] [2][8]. Furthermore, increased efficiency in farming practices, value-added approaches, sound agricultural policies and specific value chain development are needed to improve access to inputs and markets for smallholders.

2. Integration of forage legumes into cropping systems

2.1 Forage legumes in crop-livestock farming in non-tropical dry areas

Forage legumes are essential to agricultural sustainability in dryland cereal-growing areas of the world where grazing livestock is a dominant enterprise. In dry areas where livestock are an integral part of the production system, forage legumes have increased crop yield and animal production [9] [2][8][10]. Legumes can be inserted into crop rotations in various ways depending on the production system, site-specific needs, farmer capabilities, and the amount of precipitation received. As conservation agriculture gains momentum in the dryland areas, there is potential for better integration of forage legumes into cereal based-cropping systems [11]. Based on one of three principles of conservation agriculture, diverse rotations, farmers are encouraged to grow forages legumes to avoid pest and weed pressures and improve soil quality. In addition, cereal–legume rotations extend the time during which the soil remains covered, and thus less prone to erosion and water loss.

In the dryland farming system of the Mediterranean region, several long-term barley- and wheat-based rotation experiments evaluated the value of forage legumes [11] [2]. Results demonstrated that forage and grain legumes are excellent alternatives to continuous cereal cultivation or cereal–fallow rotations in Mediterranean-type climate areas, leading to more efficient and sustainable cropping systems. The increased efficiency was also highlighted in a long-term study that compared yields and profitability of wheat (*Triticum aestivum* L.) when grown after wheat, fallow, a grazed mixture of medic species (*Medicago* spp.), and common vetch (*Vicia sativa* L.) cut for hay, over ten growing seasons in Syria [2]. It was reported that wheat after lentils were generally lower (2.22 t ha^{-1}) than after vetch (mean 2.56 t ha^{-1}) and after medic (2.40 t ha^{-1}). Inclusion of grain legumes in the rotations boosted profits significantly

because of their high grain prices and valuable straw. Replacing fallow with vetch for hay production increased the average gross margin by US\$126 ha⁻¹ year⁻¹, and growing vetch for hay in rotation with wheat produced greater profit than continuous wheat, by \$254 ha⁻¹ year⁻¹. Similarly, on-farm trials in Tunisia have shown that replacing weedy fallows with forage legumes like vetch or sulla (*Hedysarum coronarium* L.) increased productivity under conservation agriculture [12]. The dry matter production (DM) of sulla averaged 6.2 t DM ha⁻¹ with a crude protein content greater than 17%. Similarly, DM production of vetch and vetch/cereal mixtures ranged from 3.0 to 5.0 t DM ha⁻¹, as compared to weedy fallows that produced only 1.0 t DM ha⁻¹, illustrating the clear advantage of forage [12].

2.2 Forage legumes in crop-livestock farming in the semi-arid tropics

Research is also demonstrating the potential of using forage legumes in crop-livestock systems in the semi-arid regions of Eastern Indonesia. Livestock production in this region is constrained by low quality and unreliable availability of forage during the dry season, while yields of stapled cereal crops (rice and maize) can be increased by improved nitrogen supply. The herbaceous forage legumes, *Clitoria ternatea*, *Lablab purpureus* and *Centrosema pascuorum*, have shown to be well adapted and can be grown in either rotation or relay systems following either wet-season maize, or rice crops where irrigation water is limited or unreliable. Grain yields of a following maize crop were increased by 50% (1.4-1.6 t ha⁻¹) where legume was cut and removed, and by 90% (2.6-2.8 t ha⁻¹) where legume biomass was retained; the persistence of these benefits in subsequent years is being assessed [13]. This demonstrates that the transfer of nitrogen to subsequent crops is significantly diminished where legume material is cut and removed, as is often the case in smallholder cut and carry systems. Devising ways to enable livestock to graze the legumes directly is likely to enhance the N benefits provided by legumes to subsequent crops.

In addition to these herbaceous legumes, leguminous shrubs such as *Leucaena* can provide higher quality forage during the dry season in a variety of ways to improve cattle production. They can be used to enhance cattle fattening growth rates, but may also have value in other cattle systems. In some regions cattle are free-grazing, but a penned at night, where supplementing with small amounts of legume hay (1% of body weight) during the dry season enables cows to maintain body weight and condition, while unsupplemented cows lost 5% of their body weight. This is likely to have impacts on their subsequent fertility and calving interval, though this has not yet been shown. High mortality rates and low growth rates of Bali calves have been found in Eastern Indonesia, but this can be improved with grass hay and concentrate (18% CP), but this is expensive and complicated [14] [15]. Forage legumes have the potential as a cheaper alternative to a concentrate ration and preliminary studies have shown similar benefits for calf growth rates.

A series of experiments in Indonesia demonstrated that Bali (*Bos javanicus*), Ongole and Brahman (both *Bos indicus*) cows can all maintain weight on rice-straw based diets with small levels of supplementation [16] [17] [18]. Tree legumes such as *Gliricidia sepium*, *Leucaena leucocephala* and *Sesbania grandiflora* fed at approximately 0.3% liveweight (3-4 kg fresh weight) provided sufficient energy for maintenance, although the amount of supplement fed would need to be increased for cows in the late stages of pregnancy, lactating or being used for draught [19]. Even at low levels of inclusion in the diet, tree legumes comfortably meet the rumen degradable N requirements of cattle, without the risk or cost of feeding urea. Tree legumes provide a cheap and locally supplement for livestock throughout the year, including the dry season, and can be planted as living fences around the farmer's house or animal pens, where they can be harvested easily with little labour cost.

3. Utilizing trees and shrubs in forage systems

Alley cropping is a type of agroforestry in which trees or shrubs are planted simultaneously in rows with agricultural crops. It can be applied to improve forage production, mitigate drought, serve as a windbreak

and capture windblown sediments in dry areas. The incorporation of trees or shrubs into farming systems may also have environmental advantages such as the lowering of the water tables causing secondary salinity, increasing functional diversity and improving soil stability [6][20][21]. Shrubs can be directly grazed or palatable tree fodder can be cut during autumn or winter-feed gaps. This can reduce supplementary feeding costs and increase paddock carrying capacity, enabling farmers to increase animal and crop production from the same land area [22][23]. Once mature, trees and shrubs can be pruned after grazing and used as a green manure or mulch to improve soil organic matter and improve crop growth. Grazing can enhance the production of woody material and proper pruning can increase the growth of green forage, extend plant longevity and improve fodder quality [23].

3.1 Alley cropping in productive soils

Saltbushes (*Atriplex nummularia* Lindl., *Atriplex halimus* and *Salsola vermiculata*) are commonly planted in arid areas of the southern Mediterranean region. They have many advantages because of their wide adaptability to harsh agro-climatic conditions and ability to grow for a longer period than many other crops and forage species. As they require little care after establishment, their production cost is low [24]. *Atriplex* species are used to fill the summer/autumn or early winter-feed gap typical of Mediterranean-type climates in southern Europe [25], southern Mediterranean [22] [26][27]. *Acacia cyanophylla* is often used in North Africa as it fixes nitrogen and provides edible leaves for livestock. In Central Asia, *Morus alba* L. and *Morus nigra* L. are commonly planted as hedgerows and their leaves can be fed to livestock. Another well-adapted species to the cold temperature of Central Asia is *Haloxylon ammodendron* that can tolerate direct grazing [28].

In south Mediterranean, studies on alley cropping systems showed that barley grain and straw yields had significant (20-100%) increases when cropped with *Atriplex halimus* L. in alley cropping systems as compared to mono-cropped barley [23]. In another study, the agronomic benefits of the cactus-barley alley cropping system were evaluated in Tunisia [29]. Similar to the results reported by [23], total biomass (straw plus grain) of barley cultivated between the rows of spineless cactus increased from 4.24 to 6.65 t ha⁻¹ and the grain from 0.82 to 2.32 t ha⁻¹ as compared to barley alone. These results were attributed to the change of the micro-environment created by alley-cropping with cactus, which created a beneficial 'wind breaking' role that reduced water loss and increased soil moisture. The barley crop stimulated an increase in the number of cactus cladodes and fruits, while the cactus increased the amount of root material, contributing to the soil organic matter.

The alley-cropping system with *Atriplex nummularia* L. also proved efficient in the semi-arid regions of Morocco (annual rainfall 200-350 mm). Barley was cropped using a seeding rate of 160 kg ha⁻¹ between *Atriplex* rows planted at 333 plants ha⁻¹. Compared to the farmers' mono-cropping system, dry matter consumable biomass yield of *Atriplex* was significantly higher in the alley-cropping system and was more profitable than mono-cropping. [30] determined the net benefit from *Atriplex* monocropping and barley-*Atriplex* alley cropping over 15 years were 732 \$ ha⁻¹ and 3,343 \$ ha⁻¹, respectively. The assessment of alley cropping system indicated that this technology is agronomically feasible and economically profitable. Thus, system should be extended on a larger scale in the agro-pastoral areas of North Africa and West Asia.

3.2 Use of shrubs in saline and arid areas

The area of human induced salinity is increasing rapidly and a major constraint to livestock production in many areas. Shallow water tables that are associated with poor irrigation practice is another major constraint to forage production. Only few plants can tolerate the combined stresses of salinity and waterlogging [31]. It is estimated that 5% of the world's land surface is cultivated salt-affected land, which includes 19.5% of irrigated agricultural land [32] [33]. A large proportion of salt-induced soil degradation occurs on land used by smallholder farmers, who are dependent on this resource for food and

feed needs [34]. Considering the reliance of smallholder communities on saline waters and salt-affected soils for their livelihoods, direct and indirect impacts of salinity are often borne by the most vulnerable sectors of the population. In the past 15 years, there has been a concerted effort in to identify plants that can persist in saline, waterlogged and/or arid areas while providing nutrients for ruminants during critical feed gaps [35]. This work has largely focused on halophytic shrubs such from the Chenopodiaceae family as *Atriplex*, *Mariana* and *Rhagodia* species as they are naturally found in arid areas and are tolerant of salinity and aridity [36].

Halophytic shrubs are not ideal as a sole diet due to low to moderate digestibility of the organic matter, excessive salt and/or sulphur accumulation and production of plant secondary compounds such as oxalate or saponin [37] [38]. They tend to be used as a drought reserve or to fill annual feed shortages within grazing systems [39]. It is therefore recommended that farmers supplement ruminants grazing these shrubs with crop residues, hay or grain [21]. Despite these limitations, shrubs offer a valuable source of crude protein, sulphur, vitamin E and minerals within meat and wool production systems [40] [41]. There is ongoing work in Australia to select genotypes of *Atriplex nummularia* and *Rhagodia preisii* with higher nutritional value and improved 'palatability' to livestock [42]. Elite genotypes have been commercialized in Australia and testing of this material is being undertaken in Afghanistan, Tibet and Pakistan. Preliminary results from Afghanistan indicated that these elite genotypes can be successfully grown in marginal areas and have high potential to reduce the widespread feed shortage in Afghanistan [43].

4. Dual-purpose ('graze and grain') management of cereal crops

One area that has received little evaluation in smallholder production systems is the dual-purpose use of grain crops, where they are grazed during their early vegetative stage and later harvesting the grain and straw at maturity. Within a systems context, grazing crops can enable other pastures to be rested, thus increasing productivity of the whole-system [44]. This has been a common farmer practice in mixed farming systems in many developed countries [45] [7]. [7] summarize a range of reported studies and find consistently greater economic returns for dual-purpose cereal and canola crops compared with a grain-only option, particularly in dry seasons. However, the bioeconomic efficiency of dual-purpose management of cereal crops has not been widely assessed in developing world. Especially in the southern Mediterranean, where soil degradation, poverty and food insecurity are prevalent, adoption of dual-purpose management can provide desirable livelihoods outcomes.

Depending on the environment, grazing intensity and timing, and the resilience of plant species to grazing, satisfactory grain production can be obtained from dual-purpose cereal crops. Grazing at the tillering development stage does not necessarily reduce grain or fodder production [46] [47] and in some cases may even increase crop yields. For example, in a field trial in Tibet, [48] reported that cutting barley during the season to simulate grazing resulted in an increased grain yield of 0.9 t ha⁻¹. They hypothesized that the reduced plant height caused by cutting reduced lodging, which is a big problem for farmers in this region due to variety, management and seasonal conditions. Studies conducted in north-west China, have shown that cutting timing and height greatly influence the capacity of a wheat crop to respond after defoliation, with significant trade-offs between forage provision and grain yield recovery [49]. This seems to be particularly severe where crops have only a short period in which to recover while in longer season environments, the trade-off is less. Grazing of immature cereal crops (before stem elongation) may also have a positive impact on the nutritive value of the regrown forage material [50][51][52]. Given the widespread use of cereal straws in the diets of livestock in the West Asia-North Africa region, any improvement in the feeding value of these crop residues would have substantial effect on ruminant productivity.

The high nutritive value of immature winter annuals is aligned with the most productive period of growing lambs[44][53]. For example, [54] reported that crossbred lambs that grazed winter wheat had impressive liveweight gains (320-360 g/day) in Australia. Similarly, early spring liveweight gains of weaned merino lambs that consumed wheat (227 g head/d) and oat (221 g head/d) from tillering to booting stage were similar to the liveweight gains of lambs fed on a concentrate feed diet (256 g head/d) in Turkey [53]. At the vegetative phase, the energy content of dual-purpose crops is consistently measured at greater than 12 MJ ME/kg DM [35]. An issue when grazing crops is spatial variation in grazing intensity. Recent work in Australia found that preferred grazing areas could be manipulated through the use of a mineral supplement to attract sheep from over- to under-utilised areas of a wheat crop [55]. This could be a useful and practical grazing management practice in developing world where fencing to control grazing is not used in small segmented farms.

5. Crop residues and straw-based feeding

5.1 Stubble grazing, management and land tenure in WANA

Crop residues are a valuable livestock feed resource through the developing world. They are widely available, cheap to purchase, and can be stored for long periods to meet periods of feed shortages or reduce daily labour requirements for cutting feed for livestock. Over the last three decades, the feed gap has become more acute because of increased sheep numbers and expansion of cereal mono-cropping at the expense of food and forage legumes and rangeland resources in the south Mediterranean[9][56]. Consequently, cereal stubbles and straw have become the primary source of feed for small ruminants in the region [40][8]. Stubble grazing practices in the Mediterranean basin often lean towards intensive, high stocking rate methods, leaving soil barren. These intensive grazing practices also damage soil structure, create compaction, and lower the soils capacity to capture rainwater [57]. Although crop residues are perceived to be the essential nutrient source during the summer months, the dry matter intake and nutritional quality of the stubble decreases linearly with an increased number of grazing days and stocking rates [58][59]. Immediately after harvest, higher quality plant parts (leaves and some grain) are inadvertently left on the field. These higher quality materials have been shown to benefit livestock in liveweight gain, but animals consume these materials in a few weeks depending on the stocking rate [39]. Thus, the feeding value of stubbles declines over time and there is a point where the high-value components have been eaten and high fibre content of remaining stems will constrain intake to sub-maintenance levels. Provision of energy, protein and mineral supplements is required to utilize the remaining stubble.

5.2 Straw-based feeding in in the semi-arid tropics

Crop residues such as rice straw and maize stover often provide the bulk of livestock diets. However, they have low digestibility, and do not contain sufficient metabolisable energy (ME) or crude protein (CP) to maintain animal liveweight. Large amounts of research has been conducted to try to improve the feeding value of cereal straws through treatment with additives such as urea, ammonia and enzymes. These treatments have not been widely adopted by smallholder farmers because they are considered costly, labour intensive, technically difficult, or potentially dangerous to animal health [60]. Researchers in India have identified cultivars of maize, millet and sorghum that have higher quality stover without compromising grain yields [61] [62][63]. Supplements can be also used to increase the energy and protein content of livestock diets, but they need to be cost effective, easily accessible and practical to be adopted by farmers.

Crop by-products as such onggok (residue after starch extraction from cassava) or rice bran can also be used to provide additional energy to cattle fed rice-straw based diets. However [16] found that in Ongole cattle, feeding rice bran did not provide additional ME intake or liveweight gain compared to feeding gliricidia. It is important to note that while crop-residue based diets are sufficient for maintenance of livestock with low energy requirements, even with supplementation, they will not support high growth rates. However, by feeding rice straw to cows with low maintenance requirements, higher quality feed can be directed to high-value animals such as growing calves.

6. Socioeconomic and policy issues

Policies to promote the adoption of productivity-enhancing measures that will help improve the management of natural resources should be developed and enforced in developing countries. Improving the feed base through increased forage availability requires knowledge management, an understanding of the behavior of local communities, and the ability to communicate and reduce gender inequalities. Improved productivity and equitable access to inputs for crop-livestock production are needed to help increase household incomes as well as asset wealth and well-being through healthy livestock holdings. Recognizing that women play important roles within integrated crop and livestock production systems, greater attention must be focused on equitable access to knowledge and public and private services in the development of socially sustainable forage production systems. It is crucial to enhance national adoption of research-based recommendations through more effective linkages among national and international research systems, marketing and service providers, and farmers and consumers. Without proper technical backstopping and improved efficiency in crop-livestock production, producers in developing countries will not be able to compete with the more efficient foreign producers in either the domestic or export markets.

Understanding the whole-of-system implications of proposed technologies is also required. For example, studies have demonstrated that intensifying livestock production systems that require increased forage resources can have positive economic outcomes but can have negative impacts on food self-sufficiency and labour requirements [64]. The impact of particular technologies on both market and production risk is also often unexplored, this often requires whole-farm bio-economic modelling approaches. Furthermore, there is often a wide diversity of resource availabilities, capital access, skills and knowledge and production emphasis amongst small-holder producers. Hence, the impacts of particular technologies is likely to differ amongst them. For example, analysis of integrating forage legumes in Eastern Indonesia shows that farmers with access to underutilised land and more livestock are likely to benefit more [65].

Currently, lack of quality seed of improved forage varieties, poorly functioning seed and fodder markets, and biased national policy towards the production of strategic food grains and crops constrain the economic incentives for sustainable forage production and marketing. Redirecting subsidies on forage crops has provided successful outcomes for smallholder crop-livestock producers in various Mediterranean countries [66] [67]. Thus, public funds should be invested in supporting forage-based crop-livestock farming and research, including seed systems, rather than cereal mono-cropping or industrial-scale meat and milk production.

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